Renewable and Sustainable Energy Reviews 44 (2015) 1–11

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Energy efficiency index as an indicator for measuring building energy performance: A review

Nur Najihah Abu Bakar [a,b], Mohammad Yusri Hassan [a,*], Hayati Abdullah [a], Hasimah Abdul Rahman [a], Md Pauzi Abdullah [a], Faridah Hussin [a], Masilah Bandi [c]

[a] Centre of Electrical Energy Systems (CEES), Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM), 81310 UTM Johor Bharu, Johor, Malaysia
[b] School of Electrical Systems Engineering, Universiti Malaysia Perlis, Pauh Putera Campus, 02600 Arau, Perlis, Malaysia
[c] Office of Asset and Development, Universiti Teknologi Malaysia, 81310 UTM Johor Bharu, Johor, Malaysia

ARTICLE INFO

Article history:
Received 31 December 2013
Received in revised form
29 October 2014
Accepted 12 December 2014

Keywords:
Building
Energy efficiency
Energy consumption
Energy efficiency index (EEI)

ABSTRACT

Accurate forecasting of energy consumption in a building is an important strategy in achieving the goal of reducing energy demand, as well as to improve energy efficiency. To implement this strategy, many methods and indicators have been proposed to monitor and measure energy performance in buildings. However, various factors that influence energy consumption of a building system operation, such as the types of activities carried out in the building, weather conditions, building materials, HVAC system and occupancy; contribute to the difficulty in accurately measuring a building's energy system. This paper provides a review on the Energy Efficiency Index (EEI) as an indicator used to track the performance of energy consumption in a building. Previous research works concerning this index and relevant mathematical models are also introduced. Other related methods or indicators for measuring energy consumption performance of buildings will also be presented.

© 2014 Elsevier Ltd. All rights reserved.

Contents

* Corresponding author. Tel.: +607 5557001; fax: +607 5557005.
E-mail address: yusrihutm@gmail.com (M.Y. Hassan).

http://dx.doi.org/10.1016/j.rser.2014.12.018
1364-0321/© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Rapid development of the building sector has led to the increase in global energy demand. The development should run in parallel with energy production and energy consumption because of the limited energy resources [1]. Rising demand for energy in the developing countries has initiated greater efforts among many organizations to balance between energy generation and energy consumption. Many research works related to consumption of total energy in buildings have been carried out to share knowledge in energy efficiency and energy conservation initiatives.

Energy efficiency plays an important role in controlling energy use, as well as reducing cost and maintaining comfortable environment in buildings [2]. Energy efficiency and energy management are closely related in terms of monitoring and controlling energy consumption in buildings. With the current increase in the global energy consumption, the main concern is not only focused on how to produce the required energy but also ways to improve energy efficiency to ensure sustainable energy supply and to be able to meet the required demand. In order to ensure optimum operation of a building's energy system, energy efficiency initiatives should be carried out regularly and continuously to verify the actual pattern of the building's energy consumption. The success factor for energy efficiency initiatives greatly depends on the method or indicators used to measure the energy performance in the buildings.

For the purpose of energy sustainability and conservation, various approaches in building energy-analysis methods have been suggested. The introduction section of this paper presents an overview of the global energy demand, total energy usage in buildings, and energy efficiency initiatives in buildings. This is followed by a discussion on the development and integration of various approaches to measure energy performance in buildings by researchers in these areas in Section 3. Section 4 discusses the utilization of the Energy Efficiency Index (EEI) as a means to measure energy performance in buildings. The recent trend in the development of mathematical models for EEI is also included in Section 4.

2. Energy consumption in buildings

Energy consumption plays a vital role as the lifeline for all activities being carried out in a building. Energy production and consumption data are essential for energy conservation purposes. To better understand the problems occurring in the energy sector and to propose effective solutions, it is important to analyse where and when energy is being consumed within the facilities.

In general, final energy consumers can be classified into several main sectors, as given in Table 1. In year 2011, transportation, industrial, residential and commercial sectors contributed to 28%, 31%, 22% and 19%, respectively, as the final energy consumers in the world [3]. The trend for energy source used by end user sector in the world is illustrated in Fig. 1.

Table 1
Final energy consumers by sector in 2011.
Source: U.S Energy Information Administration (EIA).

Sector	Percentage in the world (%)
Transportation	28
Industry	31
Residential	22
Commercial	19

The building sector has been identified as the largest energy consumer as it accounts for a significant percentage of a nation's energy consumption [4]. Energy use in buildings for various countries is shown in Fig. 2 ,accounting about 40% [5] for Europe, 23% for Spain [6], 25% for Japan [7], 28% for China [8], 39% for the United Kingdom [6], 42% for Brazil [9], 50% for Botswana [10], and 47% for Switzerland [11].

Worldwide energy consumption for buildings is forecasted to grow approximately 45% starting from the year 2002 to 2025 [12,13]. According to the statistical report by IEA 2007 [14], the building sector in developed nations accounts for about 40% of the primary energy consumption. From that amount, 70% of the sources used is in the form of electricity. The report by the United Nation Environment Programme (UNEP) [15], also stated that 30–40% of the energy in the world is consumed in buildings. The proportion of energy above signifies that the building sector can be considered as one of the important sectors, as it accounts for a very high percentage in national energy consumption [6]. If this trend continues, the building sector will consume almost as much as the combination of the industrial and transportation sectors [16]. Although this maybe a cause for alarm, it does provide a good opportunity for sustainable energy planning in the building sector. Therefore, there is a need to optimize a building's energy efficiency for sustainable energy management [17].

2.1. Energy consumption distribution

The distribution of energy consumption in the building sector involves a large set of variables. The prediction of the energy consumption in a building requires a detailed description of the building, such as construction materials, geographical location, operation schedules, energy suppliers rates, air-conditioning systems, lighting and external weather conditions as input parameters [18].

Buildings are built with different standards and come in a wide variety of sizes, shapes and purposes. The Commercial Buildings Energy Consumption Survey (CBECS) classifies buildings based on the principal activity, which includes the primary business, commerce, or function carried out within each building [19]. The break-down of energy end-use in buildings for the commercial sector is shown in Fig. 3. This figure shows that the energy consumption in a building is largely dominated by the Heating, Ventilation and Air-Conditioning system (HVAC), and followed by lighting. HVAC by far is the highest energy consumer in a building [20,21]. For this reason, the US Department of Energy (DOE), in its energy efficiency program, highlights lighting and HVAC as the most common areas in which energy efficiency measures are implemented [22].

HVAC systems have always been one of the important systems installed in buildings because of the requirements for thermal comfort in buildings [23]. Fig. 4 lists various HVAC systems installed in buildings to ensure occupant's comfort. The more comfort level is being provided to the occupants of a building, the more the energy consumption [24]. Energy can be saved to a great extent by properly managing the energy while ensuring reliability of the critical loads [19], which also minimizes the total energy consumption [25].

Other than air conditioning, lighting is a common utilized form of load. It constitutes a significant portion of total energy consumption. Because of that, the researchers are continuously thriving for better efficiency of lighting systems. Jamaludin et al. [17] highlight natural ventilation and daylighting as the two strategies that should be used to reduce energy consumption especially for cooling and lighting. The US Department of Energy (DOE) in its energy efficiency program highlights lighting and HVAC as the two

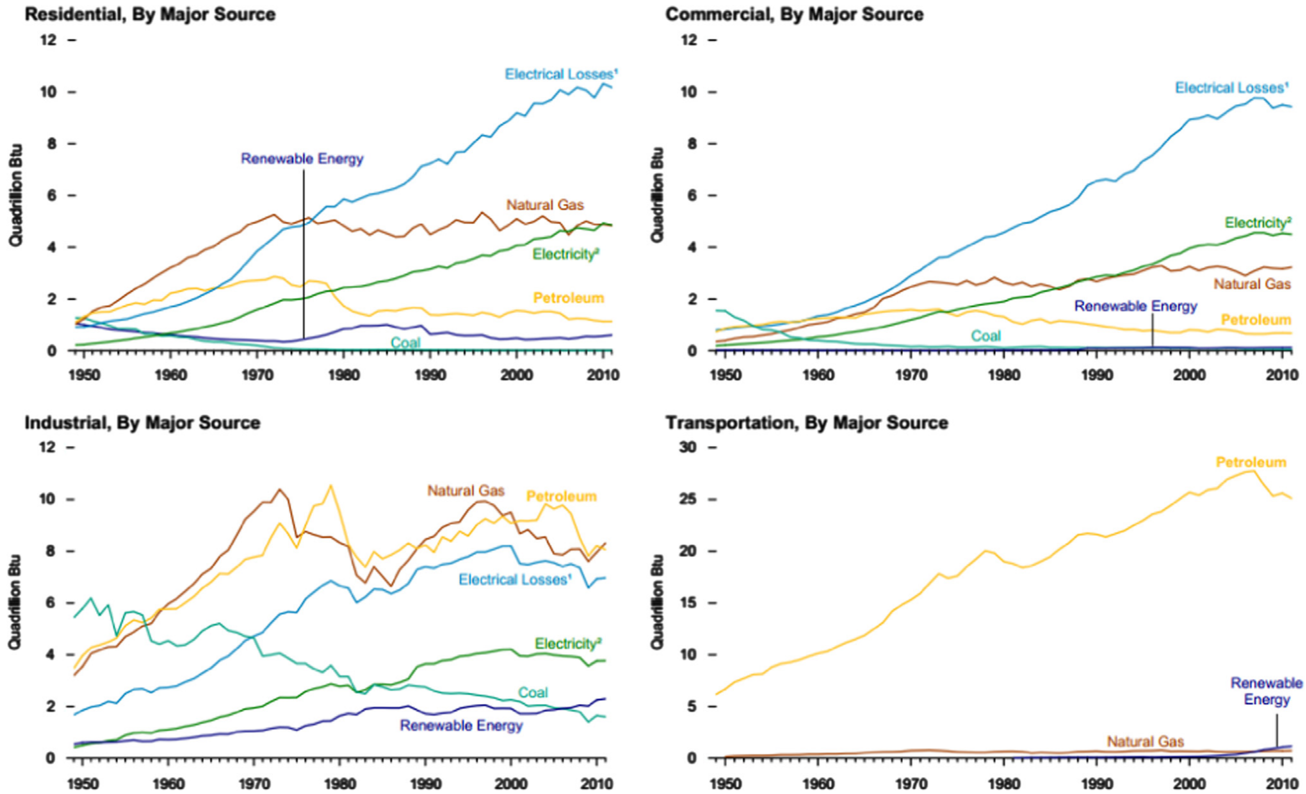


Fig. 1. Energy source used by end user sector, 1949–2011 [3].

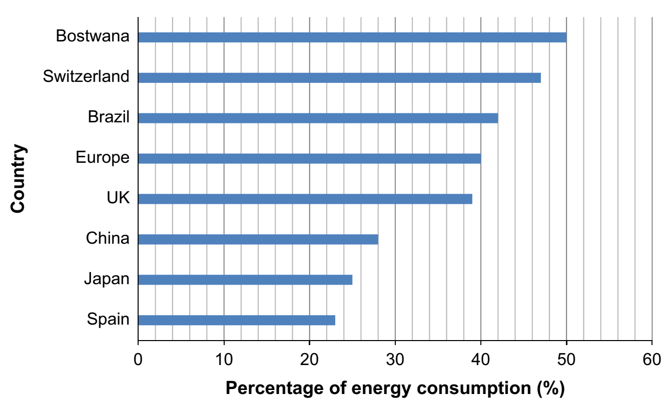


Fig. 2. Percentage of national energy consumption in the building sector.

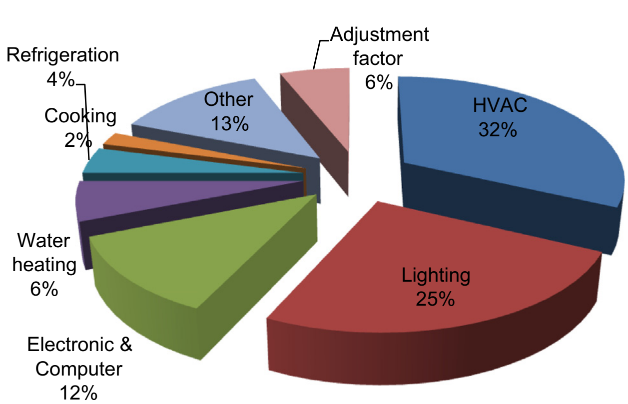


Fig. 3. Commercial Sector Buildings Energy End Use (2006).
Source: DOE, 2008 Buildings Energy Data Book, Section 3.1.4, 2008.

most common areas in which energy efficiency measures are implemented [22].

2.2. Energy efficiency

Practising energy efficiency is an important component that leads to energy saving in buildings. Energy efficiency is related to doing more work with the same unit of energy [26]. It also plays a role as a parameter that indicates the lowest level of energy usage to perform an associated task for a desired end product [2]. The concept of practising energy efficiency can be described as using less energy to provide the same outcome on a long term basis [27,28]. It can be also be seen as utilizing lower input for more energy saving [29]. Energy efficiency is also defined as the ratio between the output of the performance, service, goods or energy, and an input of energy [25]. Energy efficiency improvement from the point of view of good progress in energy end-use efficiency is an outcome of technological, behavioral and/or economic changes. Energy saving is the amount of energy saved, determined by measuring and/or estimating consumption before and after implementation of one or more energy efficiency improvement measures, whilst ensuring normalization for external conditions that affect energy consumption [25].

The increase in energy demand will contribute to the negative effect on the quality of life and environment such as global warming and depletion of the ozone layer which have a great impact on the irreversible climate change, and critical health problems due to pollution [18]. Improvement of energy efficiency in buildings has become an essential instrument not only to prevent the negative effect on the environment, but also to ensure that the energy supply would last in the long term, as well as to meet the targets set in the Kyoto protocol [18]. The following

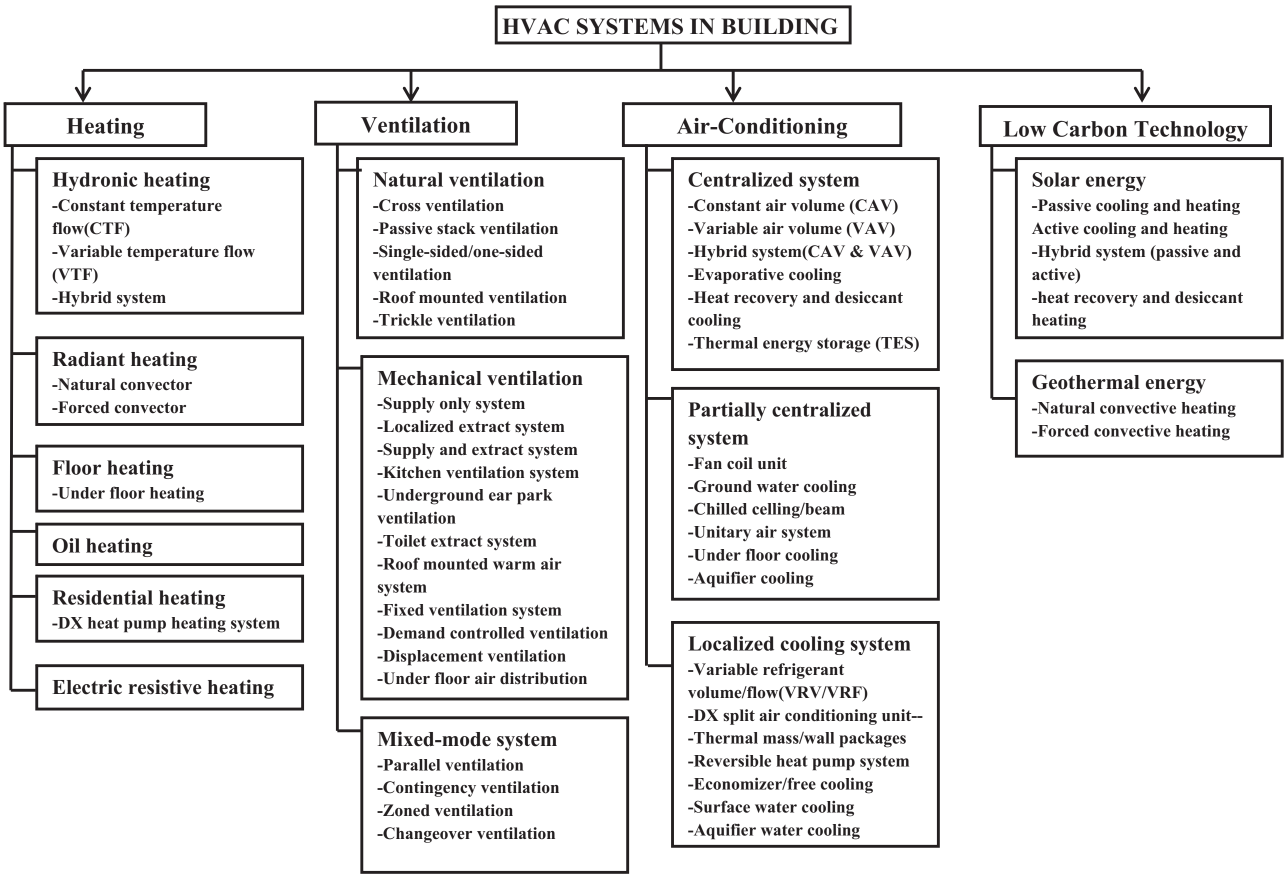


Fig. 4. Diversity of HVAC systems in buildings [2].

is a list of a building's energy efficiency potentials that are attainable [30]:

(a) 40–50% reduction of energy consumption for new buildings.
(b) 15–25% reduction in energy consumption for existing buildings.
(c) Shift of building's electricity demand from day to night to improve the load factor for electricity generating equipment in some ASEAN countries.

In order to achieve optimum energy savings, the reliance is not just on efficient devices, but also on the better use of these devices [31]. Wai et al. [1] identified three important phases towards the success of an energy efficiency program, namely 'Planning', 'Implementing' and 'Monitoring and Evaluation'. Practising energy efficiency will not only reduce energy usage in a building, but also able to reduce critical health problems [32], improve environmental problems [33], reduce carbon dioxide emission [34] and irreversible climate change [18]. Therefore, it is beneficial to both the government and energy research organizations to engage in introducing methods of assessing energy efficiency [28].

Manan et al. [35] promoted energy efficiency by using three instruments consisting of Regulation, Technical Assistance and Recognition or Incentives. These strategies need the cooperation from many parties involved including the builders, designers, producer of building materials, professional institutions, and the government [20]. Research and education also play an important role in enhancing energy efficiency programs [36]. Through research, more strategies to reduce the electricity consumption can be explored, such as by implementing load shifting method [37] and using energy index. According to Van Gorp [38], the energy saving can be achieved by consistently carrying out energy management practices and adopting recognized measurement, as well as verification procedures. However, the success of implementing energy efficiency in an organization is highly dependent on the cooperation given and commitment at all management levels.

3. Building energy analysis approaches

Over the last few decades, there has been much interest in the field of energy management, where energy efficiency projects have evolved from applying traditional practices (build-and-forget project) to effective practices involving new technologies. Building energy analysis is an initial step in developing solutions for energy efficiency. The purpose of building energy analysis is to study the performance of energy consumption, perform system comparison and identify alternatives for improvement.

Upgrading equipment and systems are some of the ways to increase energy efficiency but there is no guarantee that these practices will have good results for energy savings in the long term. However, for exhaustive energy analysis of each sub-system of the building's energy system and life cost analysis, more comprehensive tools will be required. To choose an appropriate method, various aspects need to be considered. Below are some of the factors that are usually considered when selecting an energy analysis approach to be implemented [39]:

- Accuracy.
- Sensitivity.
- Speed.
- Reproducibility.
- Ease of use and level of detail.

- Availability of required data.
- Quality of the output.
- Stage of the project.

All of the above factors have their own contribution towards energy consumption. Neglecting any of these factors might contribute to the inaccuracy of the measurements. The sections below present overviews of some of the commonly used energy estimating methods.

3.1. Forecasting method

Since the energy consumption pattern of a building involves a large set of characteristics as well as uncertainties, it is difficult to accurately predict the energy consumption of a building. It is obvious that a large number of calculations starting from the subsystem level of a building need to be performed. In recent years, several approaches of forecasting methods to predict energy consumption in a building have been proposed, such as engineering methods, statistical methods and artificial intelligence methods [5]. Engineering methods can be identified into two categories:

- Detailed comprehensive method.
- Simplified method.

Engineering methods involve using physical principles to measure thermal dynamic and energy consumption in a building. Detailed comprehensive method requires very detailed physical function to accurately calculate the building energy consumption [5,40,41]. Unavailability of some parameters may result in low accuracy of the measurements. Al-Homoud [42] proposed a number of simplified methods which can be applied in large buildings.

Statistical methods are also known as empirical methods. They are an effective approach used to analyse a number of parameters of energy consumption such as lighting, heating/cooling load, electricity consumption, electrical appliances usage and sub-level components. Utilizing statistical methods in measuring a building's energy performance requires sufficient historical performance data. Insufficient historical performance data in the past resulted in the difficulty of obtaining accurate values to predict energy consumption in a building. Numerous case studies regarding the use of statistical method are reported in the literature [43–48].

Artificial Neural Network (ANN) and Support Vector Machines (SVM) are the most widely used artificial intelligence methods to predict energy consumption in a building. Many good results in real applications have been achieved using the ANN method [42–44]. This method is good for solving non-linear problems or adopting multivariable problems in complex applications. Karatasou [49] applied the statistical analysis in building energy applications through a simple neural network, which showed that wind speed and humidity are less significant as inputs. S. Chen et al. [46] applied an alternative approach to the ANN method, namely Hybrid Genetic Algorithm-Adaptive Network-Based Fuzzy Inference System (GA-ANFIS) for predicting energy consumption in buildings.

3.2. Computer-aided analysis

Advances in computer technology make it very useful as an energy simulation tool. This systematic approach also makes it an effective means for the prediction of building thermal performance. R. Banos et al. [50] identified the energy challenges that can be tackled by implementing advanced methodologies and intelligent technologies to improve energy efficiency. Al-Homoud [42] simplified manual energy analysis methods to approximate energy use estimates using a detailed computerized hourly simulation. The application of computer technology is a very effective tool due to factors such as ease of use, user-friendly and cost effective. Computer technology can be used to perform manual calculations in a very accurate, rapid manner and requires shorter time step, which make them a widely used tool in building performance analysis.

Hong et al. [51] divided the application of computer-based tools in building's energy performance into two groups, namely Computer-Aided Design and Drafting (CADD) and computer-based simulation. Other computer-based building energy programs and system simulation tools are listed as below:

- A Simplified Energy Analysis Method (ASEAM) [42].
- DOE-2 [52].
- Building Load Analysis and System Thermodynamics (BLAST) [53].
- Transient System Simulation (TRNSYS) [54,55].
- ENER-WIN [54].
- Energy Optimization (ENEROPT) [56].

For a large building with complex energy systems, it would be unrealistic to expect that energy-efficient measurement could be carried out using “manual” calculation. However, with the capabilities of today's computers, systematic approaches represented by numerous simulation programs as mentioned above are becoming more feasible and practical in order to estimate energy performance of building, costing, utility rate, as well as utility bills.

3.3. Degree-day method

This method is known as the single-measure steady state method, which is suitable for small buildings to estimate the heating energy consumption [42]. The calculation is simple enough to be done manually, but computer programs are also used in this method. This method is very helpful in giving illustration of the current trend of energy consumption. However, there are several shortcomings of using this approach, as listed below:

1. Only efficient for heating.
2. Application is limited to residential buildings and building with structure envelope transmission and infiltration as the load dominating factor.
3. Calculation is based on average conditions and does not consider day-to-day weather variation.
4. It is a conservative method.

The calculation is performed using Eq. (1), based on the assumption that the mean daily outdoor temperature is 18.3 °C (65 °F).

$$DD_{h,m} = \Sigma_{d=1}^{Dm} (18.3 - \overline{T}_A)^+ \quad (1)$$

where $DD_{h,m}$ is the heating degree-days for month m; D_m is the number of days per month and $\overline{T}_A$ is the daily average ambient temperature.

3.4. Bin method

The “bin method” is the “hand” calculation procedure, where monthly weather data is sorted into discrete groups (bins) of weather conditions [57]. Each bin contains the number of average hours of occurrence in a month or year of a particular range of weather conditions.

For a large building such as a commercial building, the bin method is recommended because this method has the ability to

Table 2
Comparative analysis for the methods used to perform building energy consumption prediction.

Method	Scope of use	Advantages	Limitation	Input needed
Forecasting	Large building	Good for solving complex applications such as nonlinear problems	Requires very detailed and sufficient data	– Building physical data – Load consumption
Computer-aided	Large building	Easy to use and very systematic approach	The availability of simulation tool is limited	– Load consumption – Utility bill
Degree-day	Small building	Calculation involved is simple to perform manually	The application is only efficient for heating	Temperature data
Bin	Large building	The calculation is more accurate since it is based on hourly data rather than daily averages	This method requires a hand calculation procedure	Ambient temperature

perform instantaneous heating and cooling energy calculations at many different outdoor dry bulb temperature conditions (bin) [58]. This approach takes into account the load performance of HVAC systems and infiltration latent load, and is based on hourly weather data rather than daily averages, which makes it more accurate compared to the degree-day method [42].

Energy consumption is calculated for each bin outdoor temperature, and multiplied by the number of hours of occurrence of that bin [39]. The equation for the calculation is shown below:

$$Q_{htg} = UA_O \Sigma_{j=1}^{n} N_{bin,j} (T_{Bal,j} - T_{A,j})^{+}. \tag{2}$$

The heating energy used is calculated using

$$E = \frac{Q_{htg}}{n_h} \tag{3}$$

where n is the number of bins;$N_{bin,j}$ is the number of hours of occurrence and $T_{A,j}$ is the outdoor ambient temperature at the jth bin.

3.5. The prospect of aforementioned methodologies

From the overview of the four commonly used methods described in the above section to predict energy consumption in a building, it is obvious that a large number of calculations are required to evaluate a building's energy system. Nevertheless, each approach has its own advantages for use in certain cases of application.

As mentioned in Section 3.1, forecasting methods can be divided into three models, namely engineering method, statistical method and artificial intelligence method. Engineering method uses physical principles to measure thermal dynamic and energy consumption in a building. There are two variations of the model, which are the detailed comprehensive method and simplified method, which offer both very elaborate model and light-weight model for accurate calculation. The statistical method demands a detailed historical performance data. This method is easy to perform but has some shortcomings that may lead to inaccuracy and lack of flexibility in case of insufficient required data. Artificial intelligence methods such as ANN and SVM are very good in solving non-linear problems to predict energy use in building, as long as the model selection and parameters involved are well prepared. However, this method is very complicated as it focuses on non-linear problems occurring in a building.

Computer-aided analysis is a method that uses intelligent computer technology as an alternative to manual calculation. It has many benefits as a tool for a simulation process. Computer-aided analysis is also applicable for large systems such as buildings which have very complex structures because of factors such as ease of use, user-friendly, and cost effective. Degree-day method is suitable to be used for small buildings. However, the application is limited only to estimate heating energy consumption. The Bin method is recommended for large buildings due to its ability to perform instantaneous heating and cooling energy consumption calculations at many outdoor dry bulb temperature conditions. For better understanding, the comparative analysis for these methods is summarized in Table 2 below.

4. Energy efficiency index (EEI)

Quantifying normative performance of energy consumption in buildings began during the energy crisis in the 1970s. In order to secure and stabilize domestic energy supply to be in line with the Kyoto Protocol for sustainable development, the efforts to reduce national energy consumption need a building energy performance benchmark with a view to codify and standardize the best practices [59]. One of the early developed energy indices inspired by Yannas [60] is known as the 'Energy Index (EI)'.

There were also indices for buildings that are related to the climate. Early attempts by Silpasastra in India [61] and Vitruvius in Rome [62] focused on design models based on climate types. An approach based on meteorological data was proposed by Mahoney in 1965 [63]. The benefit of utilizing an energy index is that it enables the evaluation of the amount of energy that had been saved or overused in the energy system operation, which helps to pave the way for future work.

4.1. Index definition

Energy Efficiency Index (EEI), or sometimes known as Building Energy Index (BEI), is the most commonly used index as a Key Performance Indicator (KPI) to track and compare performance of energy consumption in buildings. The concept of this index is widely spread because it is beneficial to have a universal index for energy efficiency practices in buildings. Generally, EEI can be viewed as the ratio of the energy input to the factor related to the energy using component, as given in Eq. (4) [64].

$$\text{EEI} = \frac{\text{Energy input}}{\text{Factor related to the energy using component}}. \tag{4}$$

The above definition for EEI is dependent on the parameters used as the energy input and the factor related to the energy using component. In general, the EEI for a building is tied to the size of the building as the energy used is considered to be based on the building floor area [64,65]. Some researchers define EEI as the ratio between the performance in terms of energy consumption or carbon dioxide emissions of an actual building to that of a reference building [18]. Regardless of the definition, the saving targets are always based on the lowest EEI for the building.

The EEI is able to capture data of the current energy performance from several buildings to form a baseline as the benchmark for organizations intending to regularly monitor electricity consumption. These data are significant information for the initial step in managing energy in a building [66]. These data can also provide the required information to set and track energy consumption goals, generate reports and key performance indicators (KPI) [38]. There have been some published works in the literature [67,68] on baseline EEI values. Knowledge on an organization's baseline EEI could further enhance energy efficiency practice within the organization because it will then be able to track the building's energy performance and analyse the sources that contribute to high energy consumption.

4.2. Factors related to energy using component

The EEI is an effective approach to raise energy conservation awareness. It highlights trends of a building's energy use as an initiative to improve the energy use through more efficient solutions and retrofits [69]. The measurement of EEI is highly dependent on the use of energy in a particular application. As the EEI is closely related to the energy component, the energy using component is influenced by some factors [64], as listed below:

1. Weight of product produced.
2. Number of item produced.
3. Weight of raw material used.
4. Period of production.
5. Period of plant usage.
6. Number of in-patient bed per night (hospital building).
7. Number of occupied room per night (hotel building).

Since the EEI is commonly used for efficiency evaluation, if the energy identification and reflection can be done in a systematic way, then it is possible to evaluate the energy wastes and energy saving [70]. However, many challenges at different levels of a building exist when there are various parameters involved. The challenges lie in how all these parameters affect the lifetime building's energy consumption and how the energy reading can be estimated and quantified accurately. The most important data required is the energy input. Several variable and factors must be considered to develop a mapping relationship for proper EEI measurement.

Some researchers perform the EEI analysis by considering separately the different types of buildings to prevent unfair comparison and measurement between buildings, as each building does not perform the same function. Buildings are used for different purposes, such as residential houses or commercial buildings, which are reflected by the different number of occupants [68] and other differences, including the building envelope characteristics, energy consuming equipment or installations and operation hours. Other factors to be considered are geographical location and environment. All these factors need to be considered in order to maintain the energy consumption performance at the optimum level [18].

4.3. EEI model

The EEI model is a widely accepted system that has been used widely in energy auditing system to evaluate energy efficiency or energy performance in many developed countries [71]. Many approaches have been proposed in the application of the EEI model. One of the popular approaches used in analysing the EEI is the decomposition method [72–75]. In this approach, the index is decomposed into a group by a mathematical chain rule. Han et al. [29] categorized the index system into three parts: outcome index, process index and reference index. An outcome index is reflected in the energy consumption, comparison of energy consumption, number of energy-saving buildings, energy saving input and indoor comfort. The process index includes major steps of building energy conservation. The reference index comprises of the data on building gross floor area.

As the awareness on building energy saving practices gains momentum, many researchers have taken the initiative to use EEI as a building index. A study carried out by Ahmad Sukri et al. [64] showed that building's energy consumption can be significantly improved by implementing the EEI model in an energy management program. The index is expressed in kWh/m^2 which measures the total energy consumption used in a building divided by the gross floor area in square meter. The expression is shown by Eq. (5).

$$EEI = \frac{\text{Energy consumption (kWh)}}{\text{area}(m^2)} \tag{5}$$

Abu Bakar et al. [65] utilized the EEI model to compare energy consumption performance between buildings using more detailed parameters with emphasis on the air-conditioning area as the normalizing factor [68]. Moghimi et al. [21] also carried out a case study on EEI of commercial buildings based on the occupied air conditioning area. The EEI measurement varies depending on the activities carried out in the particular building, as the energy consumed and size of the gross floor area would be different.

González et al. [18] proposed an energy efficiency index, EEI_B for buildings, which relates the energy consumption within a building to that of a reference building. The objective of this index is to develop a quantitative energy efficiency metric, based on actual measurement as well as accurate prediction of energy consumption. Besides promoting energy efficiency improvement, it provides a simple calculation and avoids the use of a large set of parameters to simplify the calculation of EEI for end users.

If real data is not available, the data can be obtained through estimation using simulation tools. The EEI_B is calculated as the ratio between the performance of an actual building (AB) to that of a reference building (RB), where the performance is in terms of either energy consumption or carbon dioxide emissions, as shown in Eq. (6)

$$EEI_B = \frac{C_{AB}[\text{kWh}]}{C_{RB}[\text{kWh}]},\ EEI*_B = \frac{E_{AB}[\text{kgCO}_2]}{E_{RB}[\text{kgCO}_2]} \tag{6}$$

where C is energy consumption, E is carbon dioxide emission, AB is actual building and RB is the reference building. Different types of building can be divided into separate calculations, where the calculations for each type should be based on the surface area allocated to that type. The major concern is the availability of data for energy consumption and carbon dioxide emission for each type of building. Nevertheless, this approach of determining the EEI_B index will result in a more reliable energy efficiency index because it is capable of accepting real values of energy use. The EEI_B index is also flexible as well as user friendly as it can be easily updated whenever new data is available.

Apart from the EEI, other researchers including Bimal Kumar and Rohinton Emmanuel [76] had developed other indices that have ease of applicability. They introduced the Climate Energy Index (CEI) and Building Energy index (BEI), which can be used to classify, assess and compare any climate for the purpose of understanding climate and for use in sustainable building design. The indices are also intended to be a significant tool applicable to any building type, with any design strategy, in any location and for simple quantification of the impact of climate change on building's energy consumption. The BEI is derived from the CEI as given below

$$BEI = CEI \times OA/FA \tag{7}$$

where OA is the outside air intake (m^3/h) and FA is floor area (m^2). However, additional data such as volumetric flow rate of outside air intake (m^3/h) is required and four component loads are taken into consideration, namely heating, cooling, humidification and dehumidification. To test the validity of the CEI, it must be compared with Mahoney's Table [63].

Buildings are deliberately constructed to shelter occupants and often designed to satisfy thermal comfort in the occupied space by using mechanical heating and air-conditioning systems [42]. Significant amount of energy saving can be realized if the buildings are properly designed and if the system can operate in the most efficient way possible. Don McLean [77] worked on two energy indices similar to the Climate Energy Index (CEI) and Building Energy Index (BEI) indices used by Bimal Kumar and Rohinton Emmanuel [76]. They believed that a good building design that can provide comfort to the occupants relies on an appropriate understanding of the climate. These two indices are seen to be beneficial in providing a common basis for comparisons of building energy performance and different design strategies in a simple way. The BEI in this study was derived from the CEI as expressed in Eq. (8). However, the calculations required a high level of interpretation to be correctly utilized in the design process.

$$\begin{aligned}\text{BEI} = \text{CEI} \times (\text{Building design air flow/Floor area}) \\ + (\text{Normalized non} - \text{space conditioning benchmark load}).\end{aligned} \tag{8}$$

It is important to carry out proper standard measuring procedures to ensure that a building's energy performance can be monitored comprehensively and the savings verified correctly [38]. The EEI model is seen to be a means of ensuring that the proper measuring procedures are being carried out. A comparative analysis of commonly used EEI model is summarized in Table 3.

4.4. Case study

This section presents a number of case studies concerning to the analysis of Energy Efficiency Index (EEI) for building. Most of the worldwide organizations implement EEI analysis to their building by using kWh/m^2 approach, where energy consumption evaluations are based on per unit floor area. Moghimi et al. [21] compared the end-use energy in a large-scale hospital building in Malaysia by using this index. The case study was conducted at Universiti Kebangsaan Malaysia Medical Centre (UKMMC). EEI of this hospital was calculated and then compared to the EEI of other hospitals to measure the level of energy usage in this hospital. In Malaysia, the EEI's standard value for hospital building is estimated at 200 kWh/m^2/year. This is the baseline rating to achieve energy efficiency in the building. However, the EEI comparison in Fig. 5 reveals that this hospital had EEI value approximately 384 kWh/m^2/year, which is significantly higher than the Malaysian recommended rating standard. Thus, UKMMC requires some strategies for reducing the EEI.

A similar study but for different types of building was reported in [78], where it provided an overview of the Life Cycle Energy Analysis (LCEA) using EEI concept for both residential and office buildings. The analysis includes the lifecycle energy, operating energy and embodied energy in implementing strategies for the reduction of energy consumption. Embodied energy is the energy that was consumed during the manufacturing phase of the building including building material production, renovation and technical installation. Operation energy comprises all activities related to the use of the building over its life span such as day-to-day maintaining of comfort conditions (HVAC, lighting and the need for other load appliances), water use and powering appliances. Life cycle energy is the sum of all energy input to a building in its life cycle. The operating energy and embodied energy will determine the total value of life cycle energy. This study involved 73 case studies from 13 countries, where case studies no. 1–46 are for residential buildings, while case studies no. 47–73 are for office buildings. Figs. 6 and 7 show the bar chart of EEI reading for lifecycle energy, operating energy and embodied energy for both residential and office buildings.

The case studies number had been arranged in an ascending order to facilitate the analysis. All case studies assessment is normalized to kWh/m^2/year where the building parameters used in the calculation were building floor area and also energy intensity. The range of EEI for residential buildings was between 150 and 400 kWh/m^2/year (primary) and the range of EEI was between 250 and 550 kWh/m^2/year (primary) for office buildings. This indicated that the EEI values of office building case studies are slightly higher than the residential building case studies. It is because of the higher life cycle in the office building which can be attributed to the fact that office building generally requires more operating energy due to high occupant intensity, large electrical load usage and more energy is needed to maintain comfort conditions inside the building compared to the residential building.

It can be observed that as operating energy is expressed in primary energy terms, countries which employ renewable energy such as hydro, wind and solar to their building as the alternative energy to the existing sources, have significant low energy figures than other countries which use fossil-fuel energy sources. These clean sources of energy help to reduce energy consumption in buildings; at the same time provide lower EEI. This is the actual target since the lowest point of EEI value indicates better energy consumption.

McLean et al. [77] investigated the climate impact in energy index, where the index is recognized as the Building Energy Index (BEI). The derivation of the BEI involved another energy index which is the Climate Energy Index (CEI). The purpose of CEI is to quantify the effect of the climate on building energy performance at a particular geographic location. CEI is exclusively based on climate data and operation hours in a building. The calculation of CEI depends on the psychometric chart, and the unit of CEI is in kWh/yr/(m^3/h). Fig. 8 shows the case study for both CEI and BEI for school and office buildings, based on the climate in London.

The bar chart shows that the CEI value for both buildings seemed similar. However, the CEI for the office building was actually slightly higher since occupancy hours in the office building was longer than those of the school building. In contrast, BEI with climate for the office building was lower than those of the school building due to smaller ratio of the office building design airflow to the floor area. The BEI with non-climate base has a higher value for the office building with 142.9 kWh/m^2 yr for the office building and 84.95 kWh/m^2 yr for the school building. It is believed that CEI can be a good indicator of the 'climate burden' on buildings performance. However, these approaches are still relatively complex and require a high level of interpretation to be correctly utilized in the design process.

5. Conclusion

This paper provides an overview of the published works on the methods and indicators for measuring energy performance in a building, as an effort to offer useful resources towards energy efficiency. There has been a tremendous increase in research works carried out in recent years regarding the techniques and methodologies for measuring energy consumption and related indices. Among the building energy analysis approaches that are widely used include the forecasting methods, computer-aided analysis, degree-day method, and bin method. Each method has its own capabilities to be implemented in certain cases of applications.

The Energy Efficiency Index (EEI) is currently the most commonly used indicator in the building sector for measuring energy performance. The EEI is important as a means to determine a

Table 3
Comparison model of EEI.

References	Mathematical model of EEI	Suggested baseline values	Parameters involved	Advantage	Disadvantage	Method used	Unit of EEI
González et al. [19]	$EEI_B = \frac{C_{AB}[kWh]}{C_{RB}[kWh]}$,- $EEI*_B = \frac{E_{AB}[kgCO_2]}{E_{RB}[kgCO_2]}$	– Use Spanish energy efficiency scale[75] – Have seven bands for the value of the energy certification index EEI-B $< 0.40; 0.40 \leq EEI_{B-} < 0.65; 0.65 \leq EEI_{B-} < 1.00; 1.00 \leq EEI_{B-} < 1.30; 1.30 \leq EEI_{B-} < 1.60; 1.60 \leq EEI_{B-} < 2.00; 2.00 \leq EEI_B$.	– Gross floor area – Type of building – The reading of CO_2 emission – Energy consumption – Statistical data	– Capable to accept real value and forecasting value – Not involving large set of parameters – Flexible – Can be updated in time	Data regarding energy consumption and CO_2 emissions difficult to obtain	– Calculation – Analysis – Classification	EEI_B = kWh/m^{2}EEI*B = kgCO$_2$/kWh
Ahmad Sukri et al. [61]	$EEI = \frac{EC(kWh)}{Area(m^2)}$	–	– Energy consumption – Gross floor area	– Simple calculation – Easy	–	– Calculation – Analysis	EEI = kWh/m^2
Abu Bakar et al. [62] Moghimi et al. [22]	$EEI = \frac{EC(kWh)}{Area(m^2)}$	Suggested by PTM [64] = 200–250 kWh/m^{2}Suggested by Aziz et al. [65] = 269 kWh/m^2	– Energy consumption – Air-conditioning area	– Simple calculation – Go through more detail in area – Easy	–	– Calculation – Analysis	EEI = kWh/m^2
McLean [3]	CEI calculated based on psychometric chartBEI = CEI*building airflow/floor area + normalized non-space conditioning benchmark load	Baseline BEI: – For office building = 142.9 kWh/m^2 yr – For school building = 84.95 kWh/m^2 yr Baseline CEI:For Fair-banks = 97.58 kWh/yr/m^3/hFor Singapor-e = 78.28 kWh/yr/m^3/hFor Los Angeles = 14.48 kWh/yr/m^3/h	– Floor area – Volume – Building design airflow – Non-space conditioning benchmark load – Occupancy hour	– Provide a clear intuitive understanding of basic building energy use with respect to climate impact	– Complicate	– Calculation – Simulation – Comparison of BEI – Verification of CEI through Mahoney model [60]	$CEI = \frac{kWh/yr}{m^3/h}$BEI = kWh/m^2
Bimal Kumar and Rohinton Emmanuel [74]	BEI = CEI × OA/FAOA = outside air intake(m^3/h)FA = floor area (m^2)	–	– Energy consumption – Floor area – Two sensible energy loads (heating & cooling) – Two latent energy loads (humidification & dehumidification) – Volumetric flow rate of air (m^3/h)	– BEI is simple and universal predictor of building energy performance	– Too much data needed	– Validity test – Simulation – Comparison CEI through Mahoney's Table [60]	$CEI = \frac{kWh/yr}{m^3/h}$BEI = kWh/m^2

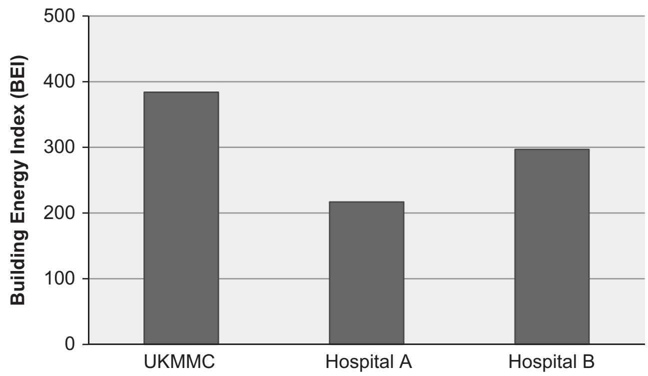


Fig. 5. EEI comparison between UKMMC and two other hospitals.

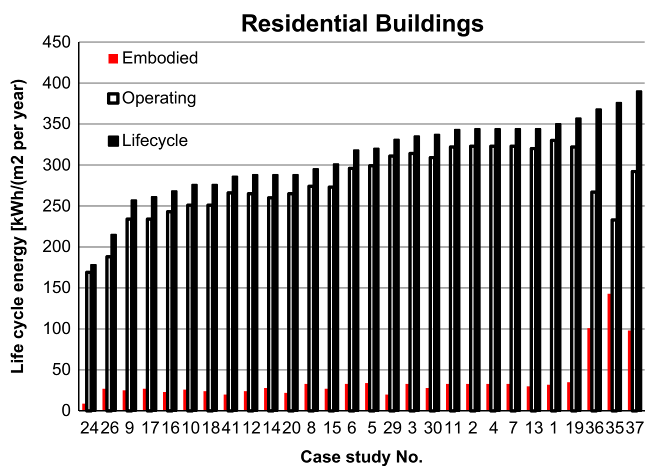


Fig. 6. Normalized life cycle energy for residential buildings (primary) [78].

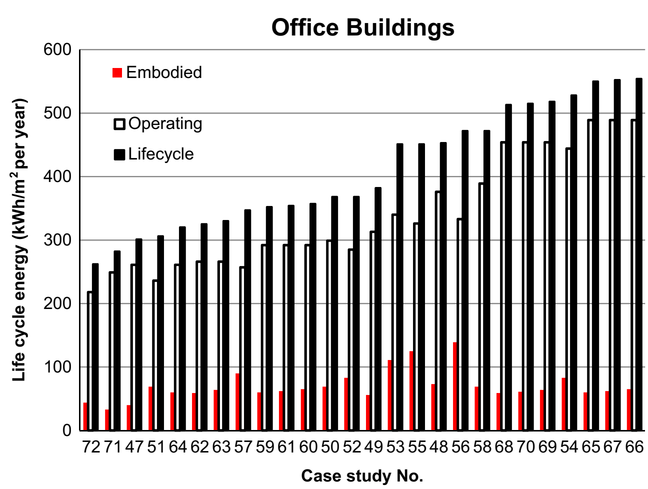
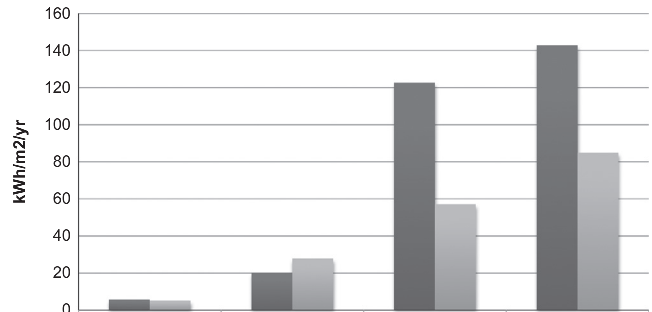


Fig. 7. Normalized life cycle energy for office buildings (primary) [78].

specific building's energy performance in terms of energy efficiency. The complex energy system in a building often involves uncertain variables. The EEI concept which offers a number of algorithm models is seen to be able to provide solutions to the complex energy system of a building. EEI is one of the tools with the capability of supporting strategic energy management systems through the prediction of energy consumption, capturing data for energy performance determination, providing standard benchmarking and verification of energy saving as well as energy waste.



	CEI	BEI_climate	BEI_non climate	BEI_total
office	5.71	20.2	122.7	142.9
school	5.16	27.8	57.16	84.95

Fig. 8. CEI and BEI values of the school and office building models (London climate) [77].

However, further research work in this field is still needed to develop standardized procedures towards the establishment of a universal index for buildings.

Acknowledgment

This work is supported by the Ministry of Education Malaysia, Universiti Teknologi Malaysia (Research University Grant (GUP) vot 00G18) and Universiti Malaysia Perlis (SLAB/SLAI scholarship award).

References

[1] Wai CW, Abdul Hakim M, Ting Low Sheau. Energy management key practices: a proposed list for Malaysian universities. Int J Energy Environ 2011;2(4):749.
[2] Parameshwaran R, Kalaiselvam S, Harikrishnan S, Elayaperumal A. Sustainable thermal energy storage technologies for buildings: a review. Renew Sustain Energy Rev 2012;16(5):2394–433.
[3] 〈http://www.eia.gov/〉.
[4] Masoso OT, Grobler LJ. The dark side of occupants' behaviour on building energy use. Energy Build 2010;42(2):173–7.
[5] Zhao H-X, Magoulès F. A review on the prediction of building energy consumption. Renew Sustain Energy Rev 2012;16(6):3586–92.
[6] Pérez-Lombard L, Ortiz J, Pout C. A review on buildings energy consumption information. Energy Build 2008;40(3):394–8.
[7] Yoon Gyu-young, Komoda H., Tanaka Hideki, Okumiya Masaya, Study on the energy conservation performance of air-conditioned system for the building combined a double skin and earth-to-air heat exchanger. In: Proceedings of the 2005 world sustainable building conference in Tokyo; September, 2005 (No. 01-102).
[8] Lam JC, Tsang CL, Yang Liu. Impact of lighting density on heating and cooling loads in different climates in China. Energy Convers Manag 2006;47(13–14):1942–53.
[9] Delbin S, Gomes da Silva Vanessa. Energy efficiency simulation of buildings in Brazil: proposal of methodology for insertion in design practice. In: Proceedings of the 2005 world sustainable building conference in tokyo; 27–29 September, 2005, No. 01-135.
[10] Ahmad AS, Hassan MY, Abdullah H, Rahman HA, Majid MS, Bandi M, Energy efficiency measurements in a Malaysian public university. In: Proceedings of the IEEE international conference on power and energy (PECon); 2012.
[11] Zimmermann M, Althaus H-J, Haas A. Benchmarks for sustainable construction —a contribution to develop a standard. Energy Build 2005;37:1147–57.
[12] Ahmed AZ. Integrating sustainable energy in building: a case study in Malaysia. In: Proceedings of the FAU conference, Copenhagen, Denmark; May 2008. p. 14–5.
[13] Klee H. Energy Efficiency in Buildings (EEB) Project; 2007.
[14] The IEA website. URL: 〈http://www.iea.org/〉.
[15] The UNEP website, URL: 〈http://www.unep.org/〉.
[16] Jiye X, Liang Y. Structure Energy Saving and System Construction. In: Proceedings of the international conference on E-Business and E-Government (ICEE); 2010.
[17] Jamaludin AA, Inangda N, Ariffin ARM, Hussein H, Energy performance: a comparison of four different multi-residential building designs and forms in the equatorial region. In: Proceedings of the IEEE first conference on clean energy and technology (CET); 2011.
[18] Gonzalez ABR, Diaz JJV, Caamano AJ, Wilby MR. Towards a universal energy efficiency index for buildings. Energy Build 2011;43(4):980–7.
[19] Smitha SD, Savier JS, Chacko FM. Intelligent control system for efficient energy management in commercial buildings. In: Proceedings of the annual

international conference on emerging research areas and 2013 international conference on microelectronics, communications and renewable energy (AICERA/ICMiCR); 2013.
[20] Mohammed A, Mustapha A, Mu'azu N. Energy efficient buildings as a tool for ensuring sustainability in the building industry. In: Proceedings of the international conference on multimedia technology (ICMT); 2011.
[21] Moghimi S, F.A., Mat S, Lim CH, Salleh E, Sopian K. Building energy index and end-use energy analysis in large-scale hospitals—case study in Malaysia. Energy Effic 2014;7:243–56.
[22] U.S. Department of Energy (DOE), 2008 Buildings Energy Data Book. Prepared for the DOE Office of Energy Efficiency and Renewable Energy by D&R International; 2008.
[23] Zhu W, Rui Y, Lingfeng W. Multi-agent intelligent controller design for smart and sustainable buildings. In: Proceedings of the 4th annual IEEE systems conference; 2010.
[24] Zhu W, Rui Y, Lingfeng W. Multi-agent control system with intelligent optimization for smart and energy-efficient buildings. In: Proceedings of the 36th annual conference on IEEE industrial electronics society, IECON; 2010.
[25] Zhu W, Rui Y, Lingfeng W. Intelligent multi-agent control for integrated building and micro-grid systems. In: Proceedings of the IEEE PES innovative smart grid technologies (ISGT); 2011.
[26] Julian DS. Energy efficiency and the environment: the potential for energy efficient lighting to save energy and reduce carbon dioxide emissions at Melbourne University, Australia. Energy 2000;25(9):823–39.
[27] Murray GP. What is energy efficiency?: concepts, indicators and methodological issues Energy Policy 1996;24(5):377–90.
[28] Saidur R, Rahim NA, Masjuki HH, Mekhalef S, Ping HW, Jamaluddin MF. End-use energy analysis in the Malaysian industrial sector. Energy 2009;34 (2):153–8.
[29] Han L, Yan Q. An approach to index system of efficacy evaluation on building energy conservation. In: Proceedings of the international conference on E-product E-service and E-entertainment, ICEEE; 2010.
[30] Kannan K., Energy Efficiency in Buildings. National Seminar on Energy Efficiency. Kuala Lumpur; 2001.
[31] Varman M, Masjuki HH, Mahlia TMI. Electricity savings from implementation of minimum energy efficiency standard for TVs in Malaysia. Energy Build 2005;37(6):685–9.
[32] Wilkinson PEA. Energy, energy efficiency, and the built environment. The Lancet. vol. 370, 9593, p. 1175–87.
[33] Lin SJATCC. Decomposition of SO_2, NO_1 and CO_2 emissions from energy use of major economic sectors in Taiwan. Energy J 1996;17(1):1–18.
[34] Ranky PG. Sustainable energy management and quality process models based on ISO 50001:2011 the international energy management standard. In: Proceedings of the 2012 IEEE international symposium on sustainable systems and technology (ISSST); 2012.
[35] Manan ZA, et al. Energy efficiency award system in Malaysia for energy sustainability. Renew Sustain Energy Rev 2010;14(8):2279–89.
[36] Denny E, O'Malley M. Building a sustainable energy future: supply and demand options. In: Proceedings of the 2008 IEEE power and energy society general meeting – conversion and delivery of electrical energy in the 21st century; 2008.
[37] Hamidi NF, Abdullah MP, Hassan MY, Hussin F, Load shifting and retrofitting strategy for reducing electricity bill. In: Proceedings of the IEEE student conference on research and development (SCOReD); 2012.
[38] Van Gorp JC. Maximizing energy savings with enterprise energy management systems. In: Proceedings of the conference record of the 2004 annual pulp and paper industry technical conference; 2004.
[39] ASHRAE, Fundamentals American Society of Heating, Ventilating and Air-Conditioning Engineers. Atlanta, GA; 1997.
[40] Kalogirou SA. Applications of artificial neural-networks for energy systems. Appl Energy 2000;67(1–2):17–35.
[41] Lee C-C, Chang C-P. Energy consumption and economic growth in Asian economies: a more comprehensive analysis using panel data. Resour Energy Econ 2008;30(1):50–65.
[42] Al-Homoud MS. Computer-aided building energy analysis techniques. Build Environ 2001;36(4):421–33.
[43] Sideratos G, Hatziargyriou ND. An advanced statistical method for wind power forecasting. IEEE Trans Power Syst 2007;22(1):258–65.
[44] Yao R, Steemers K. A method of formulating energy load profile for domestic buildings in the UK. Energy Build 2005;37(6):663–71.
[45] Ooka R, Komamura K. Optimal design method for building energy systems using genetic algorithms. Build Environ 2009;44(7):1538–44.
[46] Chen S, Li N, Guan J, Xie Y, Sun F, Ni J. A statistical method to investigate national energy consumption in the residential building sector of China. Energy Build 2008;40(4):654–65.
[47] Mindali O, Raveh A, Salomon I. Urban density and energy consumption: a new look at old statistics. Transp Res Part A: Policy Pract 2004;38(2):143–62.
[48] Reddy TA, Claridge DE. Using synthetic data to evaluate multiple regression and principal component analyses for statistical modeling of daily building energy consumption. Energy Build 1994;21(1):35–44.
[49] Karatasou S, Santamouris M, Geros V. Modeling and predicting building's energy use with artificial neural networks: methods and results. Energy Build 2006;38(8):949–58.
[50] Banos R, Manzano-Agugliaro F, Montoya FG, Gil C, Alcayde A, Gomez J. Optimization methods applied to renewable and sustainable energy: a review. Renew Sustain Energy Rev 2011;15(4):1753–66.
[51] Hong T, Chou SK, Bong TY. Building simulation: an overview of developments and information sources. Build Environ 2000;35(4):347–61.
[52] LBL, DOE-2 Engineers manual version 2.1A, LBL-11353, Lawrence Berkeley Laboratory, The National Technical Information Service (NTIS) provides DOE-2 documentation DE-830-04575, Berkeley CA; 1982.
[53] Al-Rabghi OM, Hittle DC. Energy simulation in buildings: overview and BLAST example. Energy Convers Manag 2001;42(13):1623–35.
[54] Crawley DB, Hand JW, Kummert M, Griffith BT. Contrasting the capabilities of building energy performance simulation programs. Build Environ 2008;43 (4):661–73.
[55] Oldewurtel F, Parisio A, Jones CN, Monari M, Gvalistas D, Gwerder M, Stauch V, Lehmann B, Wirth K, Energy efficient building climate control using stochastic model predictive control and weather predictions. In: Proceedings of the American control conference (ACC); 2010.
[56] Al-Homoud Mohammad S. A Systematic approach for the thermal design optimization of building envelopes. J Build Phys 2005;29(2)95.
[57] Advantages of Energy Efficiency. Available from: 〈https://www.nrcan.gc.ca/energy/efficiency/buildings/eeb/3949〉; 11 April 2014.
[58] Knebel, DE, Simplified energy analysis using the modified bin methods. American Society of Heating, Refrigerating & Air Conditioning Engineers, Inc.; 1983.
[59] Yannas S. Solar energy and housing design. Principles, Objectives, Design Guidelines, 1. London: Architectural Association Publications; .
[60] Yannas, S. Passive solar heating and energy efficient housing design. In: Proceedings of the 2nd Europen conference on architecture. Dordrecht: Kluwer; 1990. p. 548–556.
[61] Acharya PK. Indian architecture according to Manasara–Silpasastra. Patna, India; 1979. 268 p.
[62] Morgan MH. Vitruvius: the ten books on architecture. New York: Dover; 1960.
[63] Koenigsberger OH, Ingersoll TG, Mayhew A, Szokolay SV. Manual of tropical housing and building: climate design. India: Orient Longman; 1973.
[64] Ahmad AS, Hassan MY, Abdullah H, Rahman HA, Majid MS, Bandi M, Energy efficiency measurements in a Malaysian public university. In: Proceedings of the IEEE international conference on power and energy (PECon); 2012.
[65] Bakar NNA, Hassan MY, Abdullah H, Rahman HA, Pauzi MD, Hussin F, et al. Sustainable energy management practices and its effect on EEI: a study on university buildings. In: Proceedings of global engineering, science and technology conference. Dubai: UAE; 1–2 April, 2013 isbn:978-1-922069-21-4.
[66] Moghimi S, Mart S, Lim CH, Zaharin A, Sopian K. Building Energy Index (BEI) in Large Scale Hospital: Case Study of Malaysia; 2011.
[67] Aun, ACS. Green Building Index-MS125; 2008.
[68] Aziz MBA, Zain ZM, Baki SRMS, Hadi RA, Air-conditioning energy consumption of an education building and it's building energy index: a case study in engineering complex, UiTM Shah Alam, Selangor. In: Proceedings of the IEEE control and system graduate research colloquium (ICSGRC); 2012.
[69] The Johnson Controls website, 〈http://www.johnsoncontrols.com/〉.
[70] Li-Ming W, Bai-Sheng C. Modeling of energy efficiency indicator for semiconductor industry. In: Proceedings of the IEEE international conference on industrial engineering and engineering management; 2007.
[71] Cathy Turner MF. Energy performance of LEED® for new construction buildings. Washington: New Buildings Institute; 2008 (p. 2).
[72] Ang BW, Zhang FQ. A survey of index decomposition analysis in energy and environmental studies. Energy 2000;25(12):1149–76.
[73] Ang BW, Liu FL. A new energy decomposition method: perfect in decomposition and consistent in aggregation. Energy 2001;26(6):537–48.
[74] Aun ACS. Energy Efficiency: Designing Low Energy Building Using Energy, 10, Pertubuhan Arkitek Malaysia; 2004.
[75] Greening LA, Davis WB, Schipper L, Khrushch M. Comparison of six decomposition methods: application to aggregate energy intensity for manufacturing in 10 OECD countries. Energy Econ 1997;19(3):375–90.
[76] Kumar Bimal, Emmanuel Rohinton. Independent Verification of a Climate-Based Worldwide Building Energy Index; 2010.
[77] McLean Don, Roderick Ya, Quincey Richard, McEwan David. Climate Energy Index and Building Energy Index: New Indices to Assess and Benchmark Building Energy Performance.
[78] Ramesh T, Prakash R, Shukla KK. Life cycle energy analysis of buildings: an overview. Energy Build 2010;42(10):1592–600.